Magnetic springs - Fast Energy Storage for Reciprocating Industrial Drivetrains

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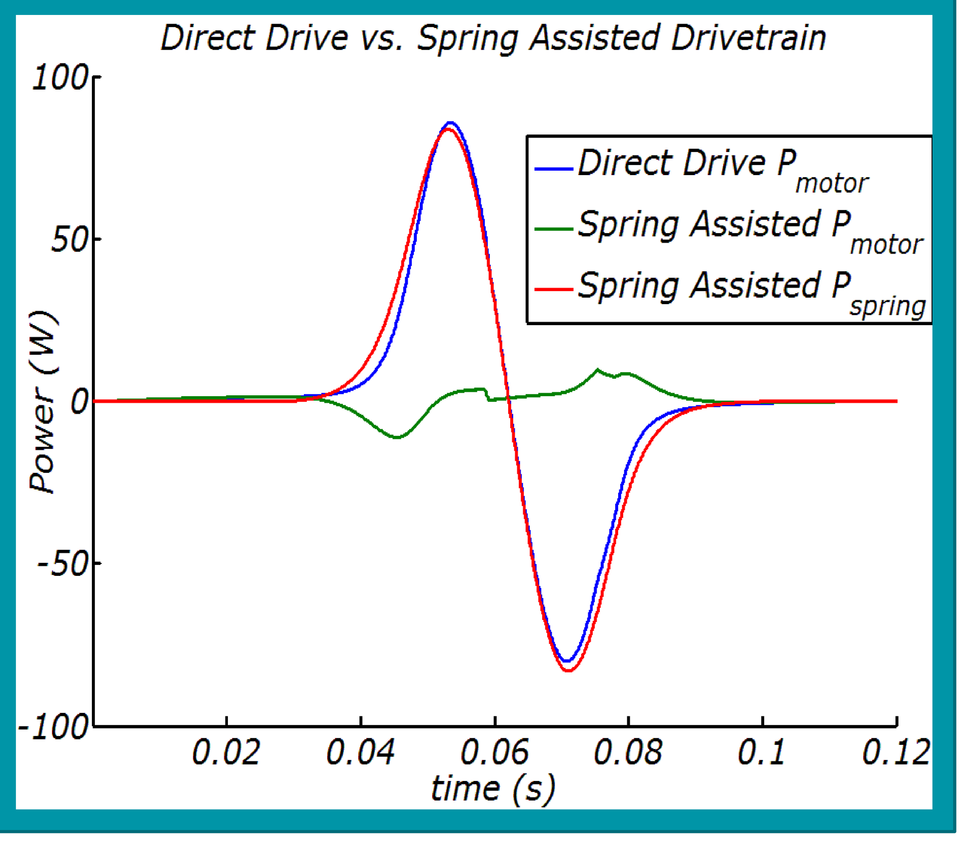
Abstract

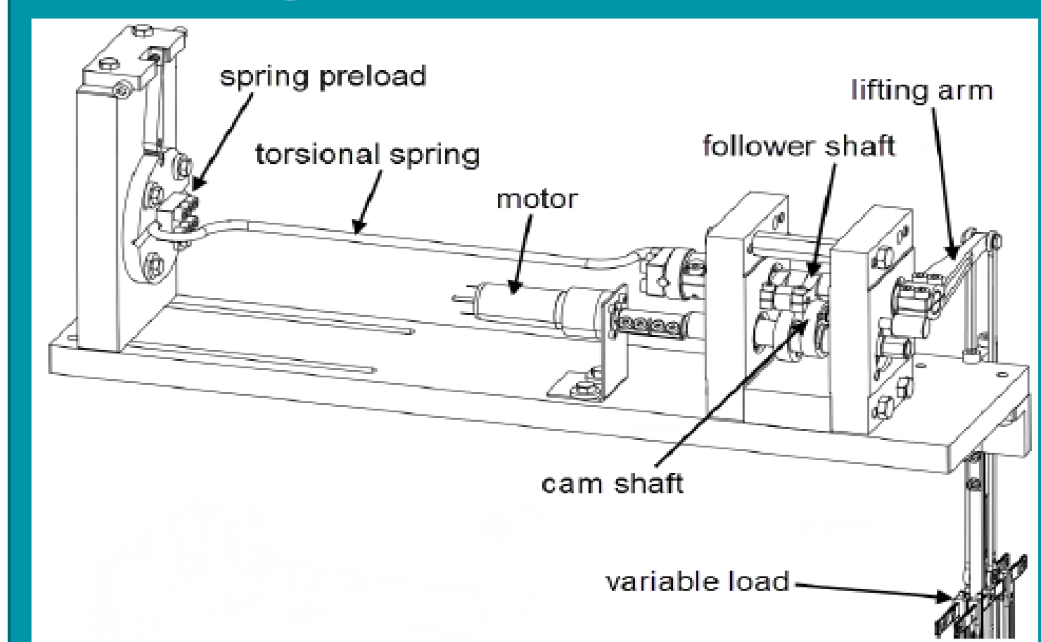
Industrial machines with reciprocating (oscillating) motion such as weaving looms tackle primarily high inertial loads, conventionally operating within frequency ranges of 5-15 Hz with relatively large strokes. Recent trends of individual electrification of parts of weaving loom drivetrains for reasons of increased flexibility of use make this problem even worse, as the inertial loads are less averaged out. Adding springs to such oscillating drivetrains can allow to improve the energy efficiency and downsize the actuators. To get an estimation of energy sinks and peak power consumption in a reciprocating drivetrain of a weaving loom, a spring assisted demonstrator available at Flanders Make has been modelled using a 1D multiphysical dynamic model. Next to energy requirements, industrial machines have strict lifetime demands. Target lifetime of 50 000 hours results in over 1E9 spring cycles. Mechanical spring design and fatigue modelling for this number of cycles is a difficult design problem with high levels of uncertainty. Therefore, magnetic springs are proposed instead of mechanical springs as a technological novelty with benefits of no material fatigue and additional flexibility in design. In the developed drivetrain model the mechanical spring is replaced by an off-the-shelf magnetic spring in order to perform a first estimation of the impact on the dynamic behavior.

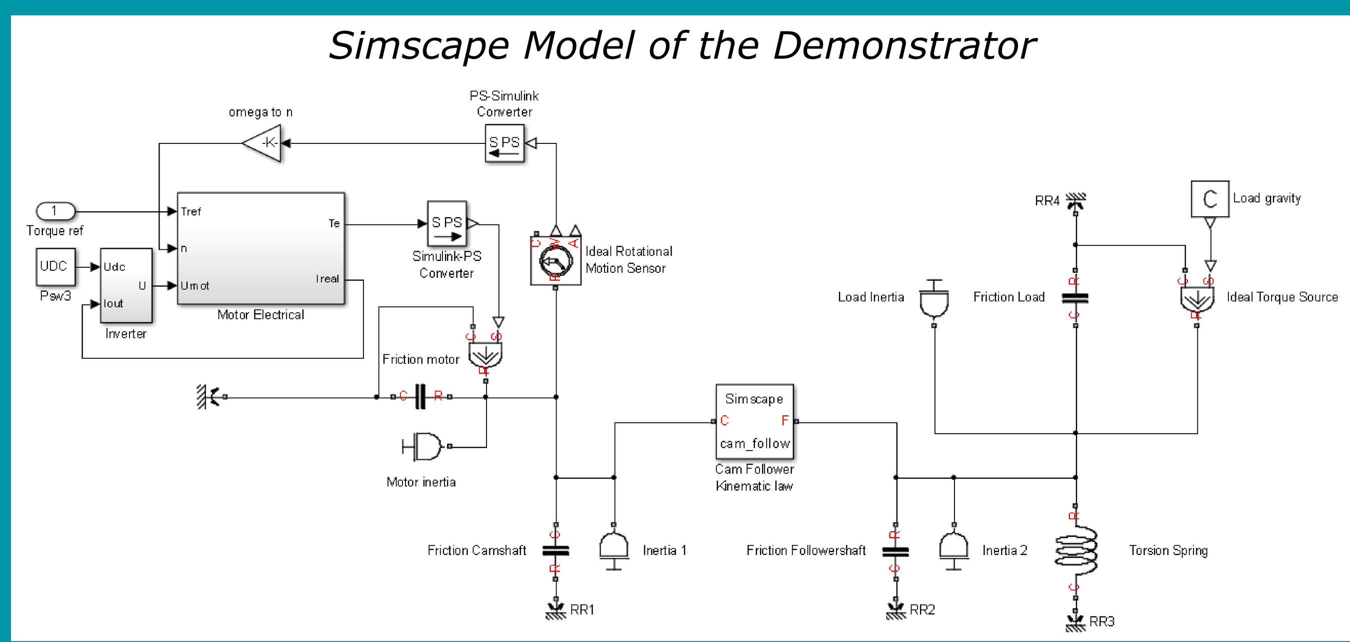
Concept: Spring assisted drivetrain

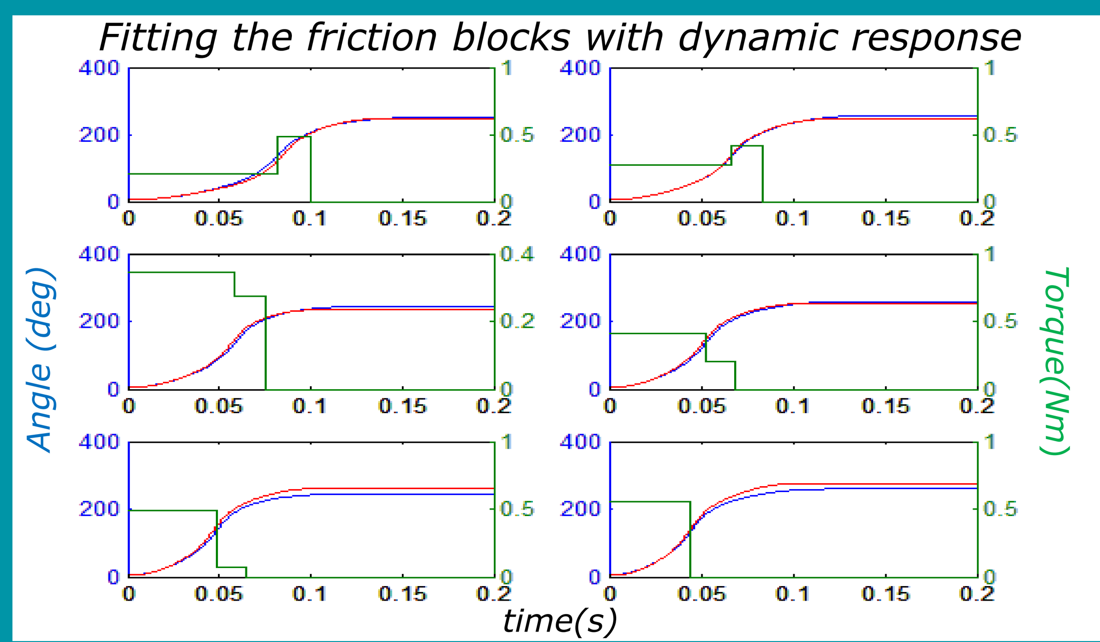
- ▲Bio-inspired concept developed in robotics for quasi-static loads[1]
- ▲***Electrical drive downsizing-cost efficient***
- ▲***Averaged power reduces losses in electrical drive***
- ▲Challenge: Robustness weaving machine drivetrain
  - ▲Control(trajectory) robustness
    - –**Dominant, dynamically sensitive, inertial load(high speeds 5-15Hz)**
  - ▲Mechanical robustness
    - –Mechanical complexity is an issue
    - –Spring is the critical component



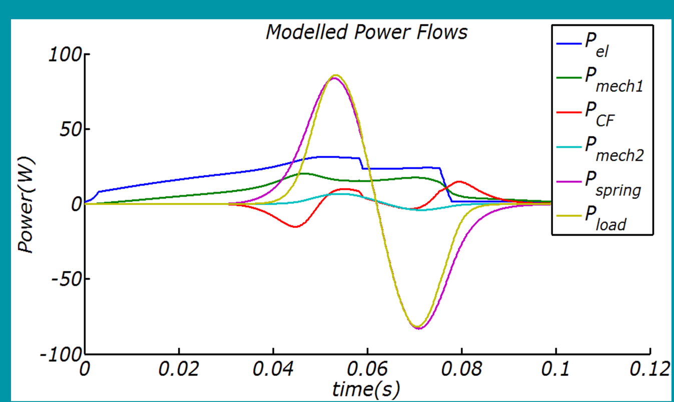
Spring Assisted Demonstrator Multiphysical Model

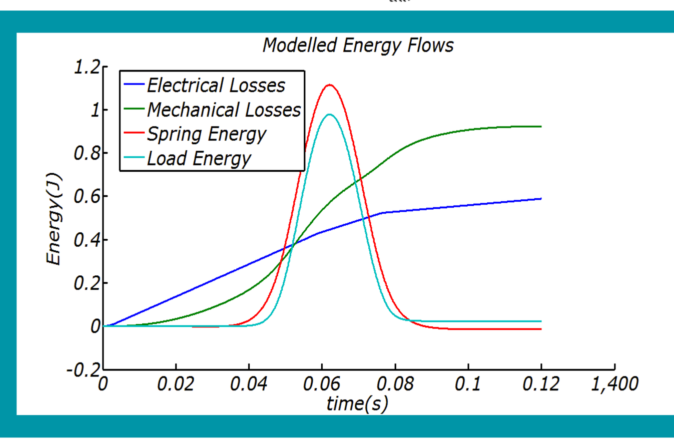






- ▲Leno selvedge spring assisted demo
  - ▲Mechanical resonance- inertial load and torsion spring
  - ▲Cam follower as a locking mechanism
    - –No braking torque needed in end position
  - ▲Order of magnitude smaller loads than weaving loom's primary motions





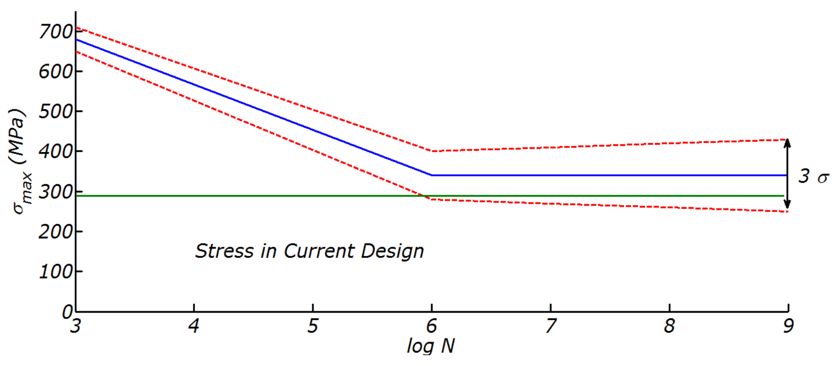
- ❑***Reactive spring power averages high power peaks***
- ❑***Electrical losses and bearing friction are dominant***

- ▲Model Bias multiple losses fitted with a single friction block
  - ▲Effect more prominent in energy than power
    - –**Dominant inertial reactive load**
- ▲Experimental validation for 6 open loop torque profiles
  - ▲Error margin position <10%

Comparison of Dynamic Behavior

Mechanical spring

- ▲Statistical S-N curve[2], fatigue limit with safety factor only for 1E6 to 1E7[3]



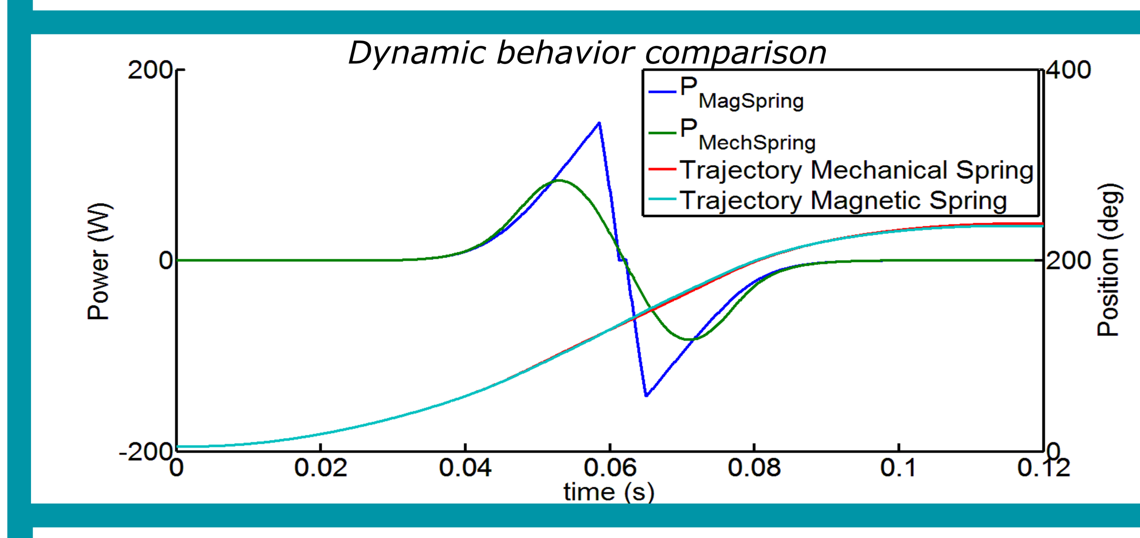
- –Uncertainty increases with N
- –expensive lengthy testing campaign, or complex models required to establish safety factors

For fixed dimensions L and spring stiffness K_{spring} there is a hard limit for stress in a torsion bar.

$$\sigma_{max} = \frac{G\theta r}{L}, K_{spring} = \frac{\pi}{2}\rho\, G r^4$$

Comparison criteria

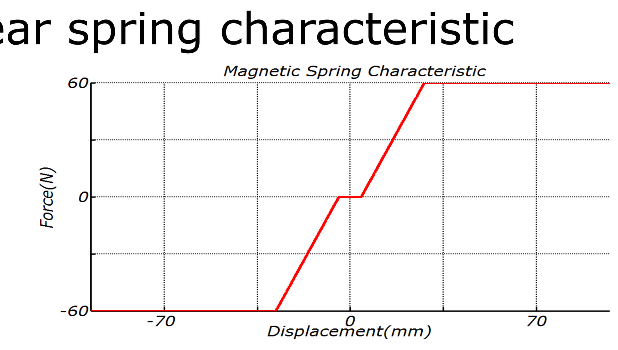
- ▲Mechanical Robustness - Goal $N = 10^9$
- ▲Inertia
  - ▲Increases load peak power
- ▲Damping
  - ▲Increases energy consumption



Despite the difference in torque profile and added inertia, off-the shelf magnetic spring offers same functionality with added benefit of extended lifetime

Magnetic spring

- ▲Off-the-shelf magnetic spring[4] conventionally used for static loads
  - ▲No material fatigue - virtually infinite lifetime
  - ▲$2.4 \cdot 10^7$ cycles and running
  - ▲Nonlinear spring characteristic



- –Design tuning- Same torque delivered per cycle + translator's inertial load ($m_T = 75g$)
- ▲Possibilities with custom designed magnetic springs[5]
  - –Higher power density if only PM are used
  - –Shapeable characteristics
  - –topological variety

Conclusions and further steps

Although experimental validation is still needed, initial models show that the magnetic spring technology provides a promising alternative solution to mechanical springs in spring assisted drivetrains for this specific operational range. In order to estimate the industrial applicability of magnetic spring technology to a wider range of specifications, accurate scaling laws for magnetic and mechanical springs yet need to be developed and compared. Improved losses analysis based on measurement and models is required for a more refined final comparison of the two technologies described on this poster.

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Acknowledgement

The authors gratefully acknowledge the European Commission for its support of the Marie Curie program through the ITN EMVeM project (GA 315967)

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EMVeM Energy efficiency management for Vehicles and Machines